Table 2. An examination of the two PI runs in Figure 6 reveals that the best control is achieved using $K_c = 0.063$ and $t_i = 0.208$, the parameters based on the open-loop frequency response. The gain of $K_c = 0.081$ derived from continuous cycling experimentation is too large and caused excessive cycling.

The PID run with Z-N settings shown in Figure 7 represents poor control. However, this should be expected because derivative action is relatively ineffective in systems containing a large effective time delay. The heat exchanger control system contains time delays associated with flow from inlet to exit, and also time delays associated with the functioning of electronic components such as the A/D and D/A converters. In fact, an analysis of the Bode plots in Figures 4 and 5 leads to the following approximate open-loop transfer function

$$\frac{E(s)}{Q(s)} = \frac{37\ e^{-0.042s}}{(0.176s+1)(0.037s+1)} \qquad (7)$$

As can be seen from the above transfer function, the loop contains an effective time delay of 0.042 minutes (2.52 seconds). This time delay is roughly 25% of the major time constant of 0.176 minutes. At the critical frequency, the effective time delay accounts for 60 degrees of the total phase lag of 180 degrees and causes crossover to occur before the smaller time constant is able to reduce the amplitude ratio. Since the resultant amplitude ratio curve is not steep in the vicinity of the critical frequency, the phase lead contributed by derivative action does not justify increasing K_c very much above the value of K_c used in PI control. This fact is apparent from the poor system response using Z-N settings with PID control.

● Optimization of Controller Setting

After completing the Z-N runs, students are required to conduct several exploratory runs to improve upon the best of the Z-N runs. The goal is to find the combination of parameters that results in the smallest error-squared integral objective function, as defined in Eq. (6). The lower limit of integration is the time of upset and the upper limit of integration is the time required for the error to drop to, and remain below, an absolute value of 0.5°C.

A partial optimization of PI control parameters has revealed that the best parameters are $K_c = 0.06$, and $t_i = 0.208$. The corresponding objective function was found to be $F = 6.97$. It should be noted that these optimal parameters are almost identical to the Z-N settings in Table 2, derived from the open-loop frequency response data. Optimization runs were not conducted with PID control. Therefore, it is possible that some derivative action might produce a smaller objective function than 6.97; however the optimal PID parameters for this control system are not the Ziegler-Nichols recomendations.

REPORT

The lab report for the experiment includes all calculations and/or analyses associated with the determination of $K_{c,max}$ and P_u. Students are also asked to construct an open-loop transfer function from their Bode diagrams and to discuss the relative merits of PI and PID control for the heat exchange control system.

ACKNOWLEDGEMENT

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ChE book reviews

FUNDAMENTALS OF HEAT EXCHANGER AND PRESSURE VESSEL TECHNOLOGY

by J. P. Gupta
Hemisphere Publishing Corporation,
Washington, DC (1986),
607 pages, $45.00

Reviewed by
Stuart W. Churchill
University of Pennsylvania

This book is entirely in the form of over 1200 questions and answers. It provides descriptions of various types of heat exchangers and pressure vessels, and also a discussion of the factors which favor the choice of one form over another for reasons of economics, safety, maintenance, *etc.* Both of these aspects are of direct interest in process design and operation. The book is said to be intended for newcomers in practice and for senior-level students. However, it will surely prove to be a standard reference even for experienced engineers.

Preliminary drafts of the various chapters were reviewed by individual experts. The list of these reviewers is virtually an honor-roll of the leaders in process heat transfer. Their participation gives this book an aura of authority over a very broad range, while at the same time the singular authorship provides a greater consistency than is ordinarily accomplished in a compilation of contributions by many authors.

The book is profusely and well illustrated, which is essential for descriptive purposes. Attention in the questions and answers is focused on the choice of various types of equipment for different applications. Although some quantitative information is given in connection with such choices, procedures of design for specific equipment are not included. Such procedures of course provide the primary content of conventional books on heat transfer and process design.

Quantities are given in English units with the SI equivalent in parentheses, or vice versa, depending on the original source. A detailed table of contents and a very complete index are essential for a book of this type in which the reader will be searching for information on a few special matters rather than reading from cover to cover. Spot tests indicate that both the table of contents and the index meet this standard, although omissions were noted in the latter. For example, the "effectiveness factor" and the "correction factor" do not appear as primary items.

Fluidized beds, direct-fired boilers, cooling towers and regenerators were arbitrarily excluded, but otherwise the book is very comprehensive. Individual topics are necessarily limited in scope and thereby incomplete. For example, the discussion of spiral heat exchangers does not mention the inapplicability of the log-mean temperature difference owing to two-way heat exchange at each point of each passage.

Despite the minor omissions noted above, this book is remarkably complete and generally sound. The format of questions and answers proves to be surprisingly successful and convenient. Students in process design will find this volume to be an essential resource, and practicing engineers will find it an invaluable reference.

The author and the publisher are to be commended for producing an imaginative and useful contribution in a mature field.

Despite the overly generous statement in the acknowledgement, my contribution to the concept was only in terms of encouragement, and to the content only as a reader. Hence, I offer the above remarks objectively as a potential user. □

PRINCIPLES AND PRACTICE OF AUTOMATIC PROCESS CONTROL

by Carlos A. Smith and Armando B. Corripio, John Wiley and Sons, $43.95, 1985

Reviewed by
Glenn A. Atwood
University of Akron

This text is designed to present classical control theory and practice to senior level students and industrial practitioners. The text focuses on single variable control loop design for continuous processes using examples from the chemical process industries. The topics covered are the same as have been included in popular chemical engineering control texts for over twenty years.

The authors have prepared a text comparable to the classic by Coughanowr and Koppel. They have succeeded in their goal of preparing a text with both principles and practice. However, with the recent advances in control theory and practice, the text should include coverage of batch process control, programable controllers, adaptive control, discrete control, distributed and computer control. Many of the above topics have been included in texts for other fields since the early to mid '70's. It is imperative that chemical engineering control texts include the more modern topics and that these be included in the curriculum. The field cannot continue to cover the same topics as were covered in the past and meet the needs of our graduating engineers or the industrial users.

The text can be divided into six major sections: mathematical basics, process dynamics, control system components, single loop control system design, and additional control techniques. The section on mathematical basics covers Laplace transforms, linearization, and complex variables. The Laplace transform and linearization sections are well-written and should provide the reader with the mathematical foundation to use the techniques in controls and other areas. The linearization section includes both single and multi-variable methods with applications to typical control problems. The section on complex numbers is very short and probably should be expanded to give students an adequate background.

Chapters 3 and 4 introduce the development of transfer functions for typical first order systems along with the system response to input disturbances.
Continued on page 97.